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# Near-Wall Velocity Field Measurements of a Very Low Momentum Flux Transverse Jet

**50<sup>th</sup> AIAA/ASME/SAE/ASEE  
Joint Propulsion Conference  
Cleveland, OH**

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Edward Coy, AFRL/RQRC**

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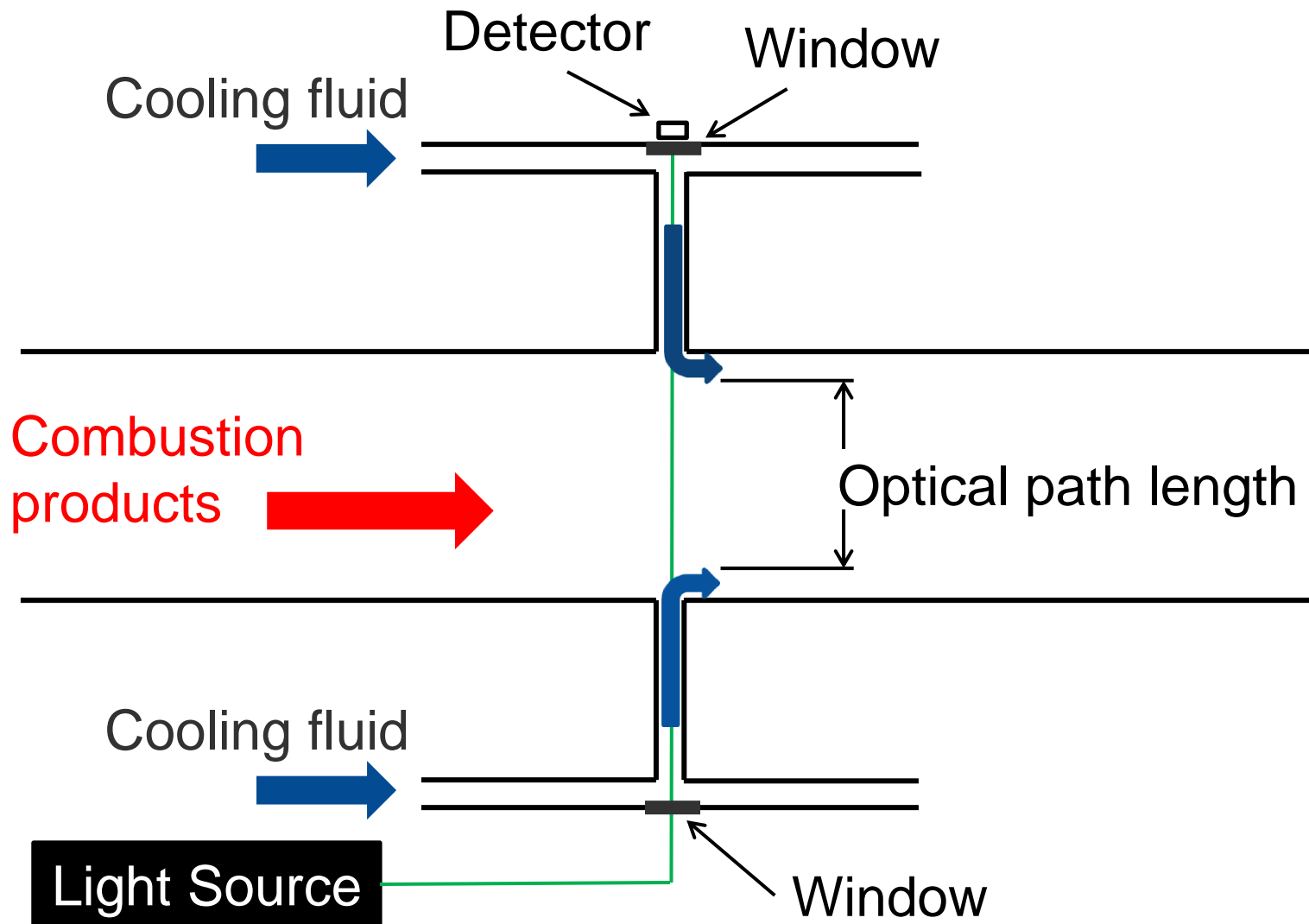
# Outline



- **Research Motivation**
- **Experimental Setup**
- **Results**
- **Conclusion**

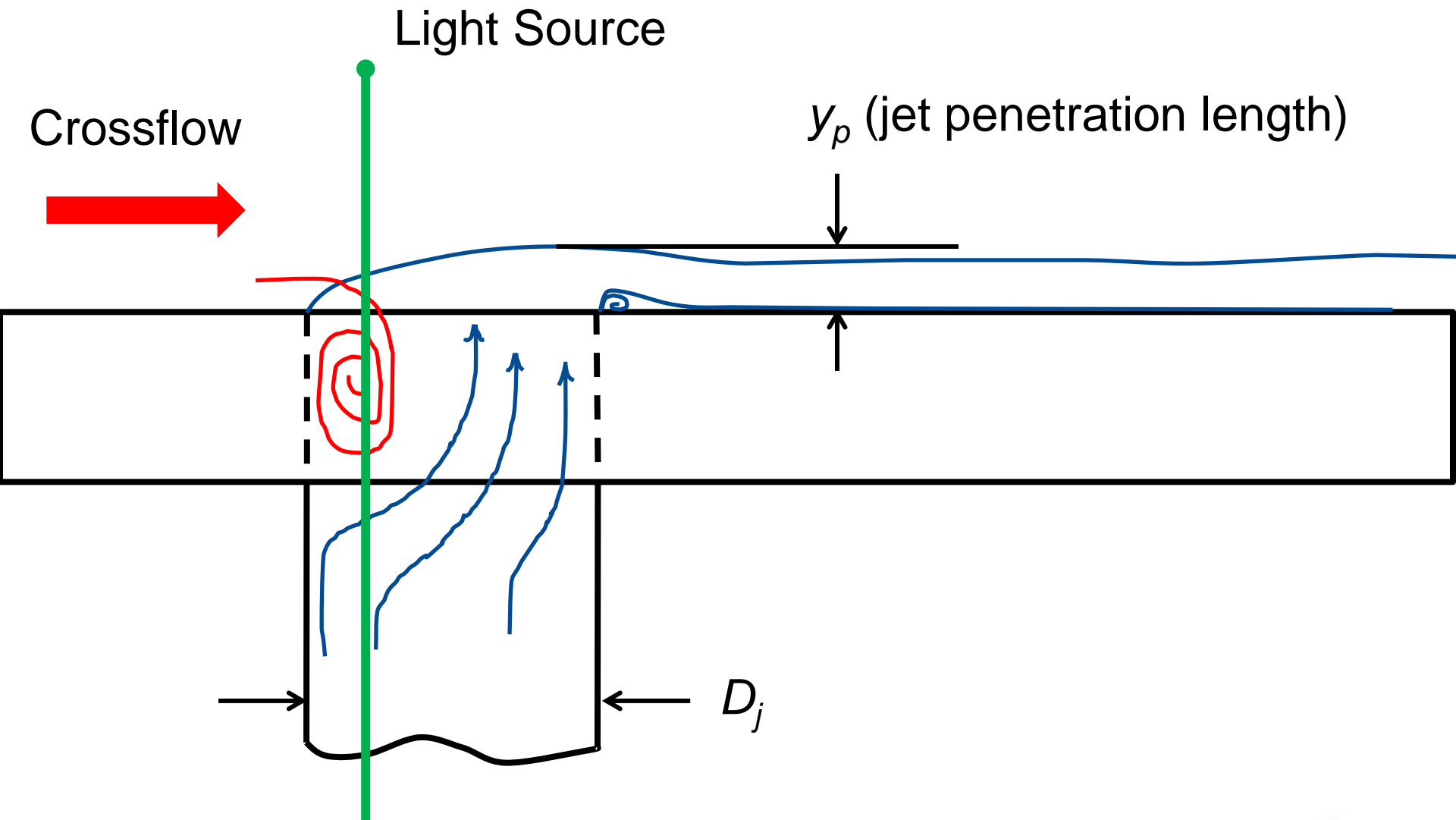


# Optical Diagnostics



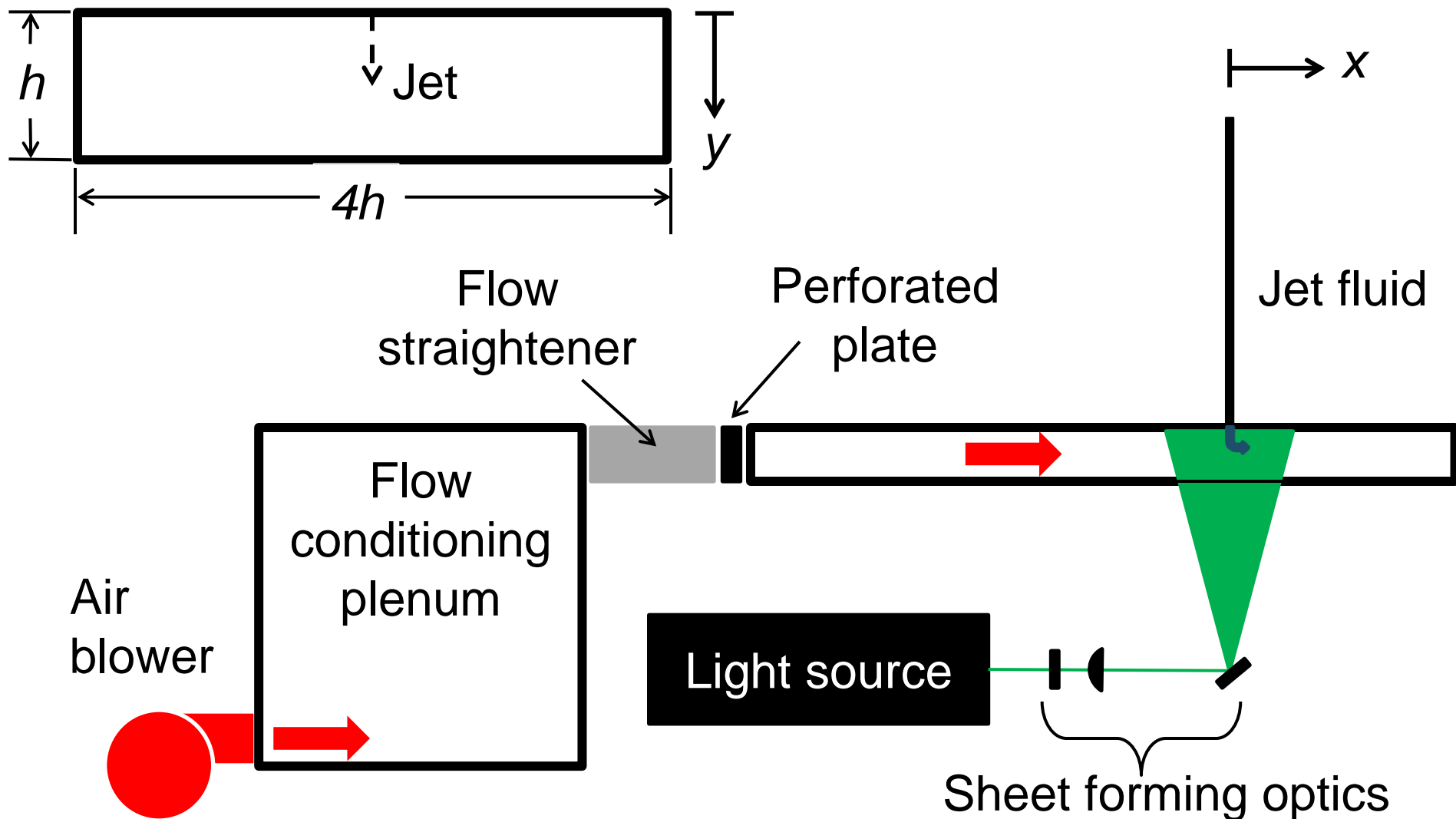


# Jet and Crossflow Interaction





# Experimental Facility

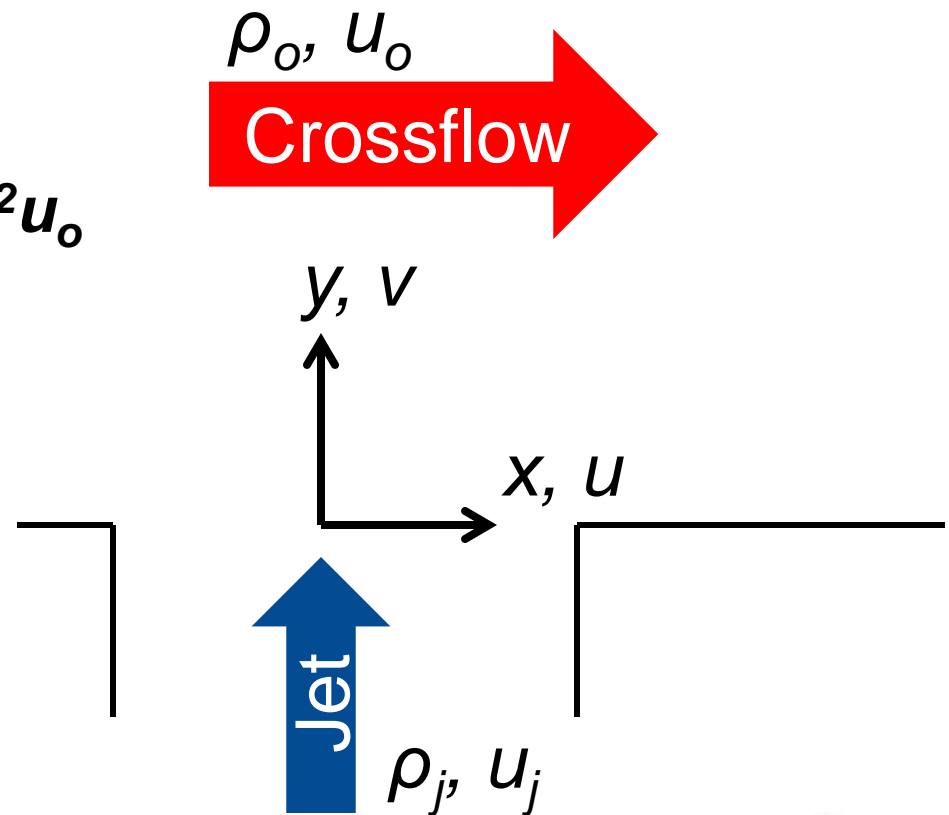




# Important Parameters



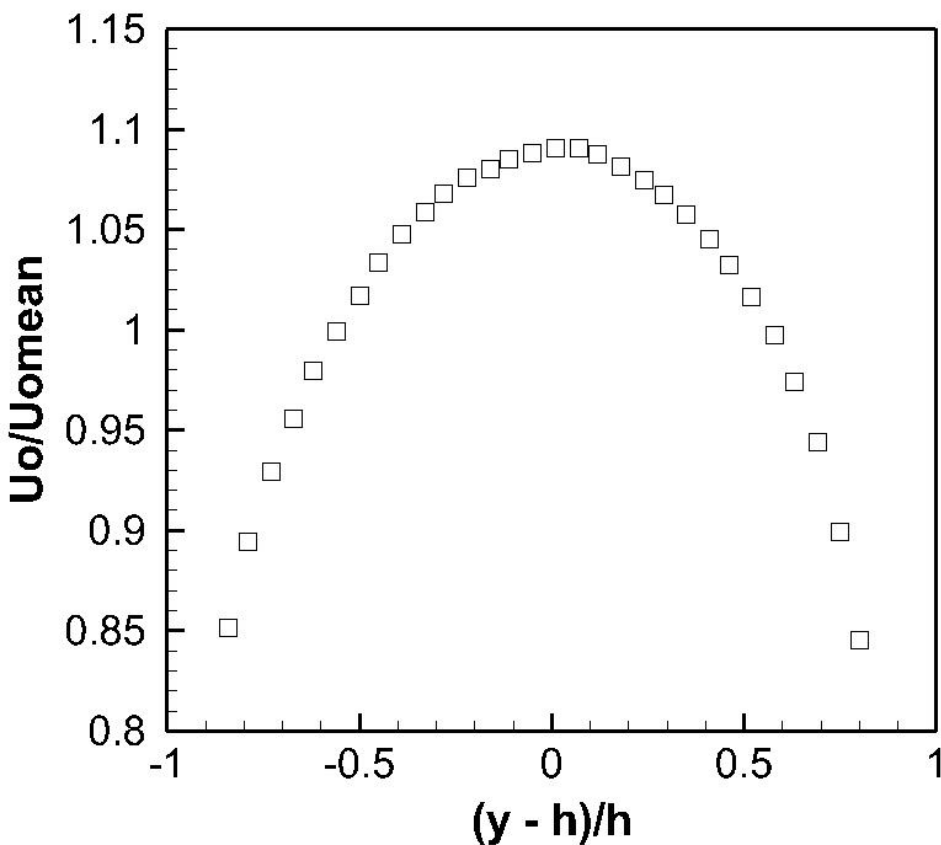
- **Momentum flux ratio**
  - $J = \rho_j u_j^2 / \rho_o u_o^2$
- **Blowing ratio**
  - $M = J^{1/2} = \rho_j^{1/2} u_j / \rho_o^{1/2} u_o$



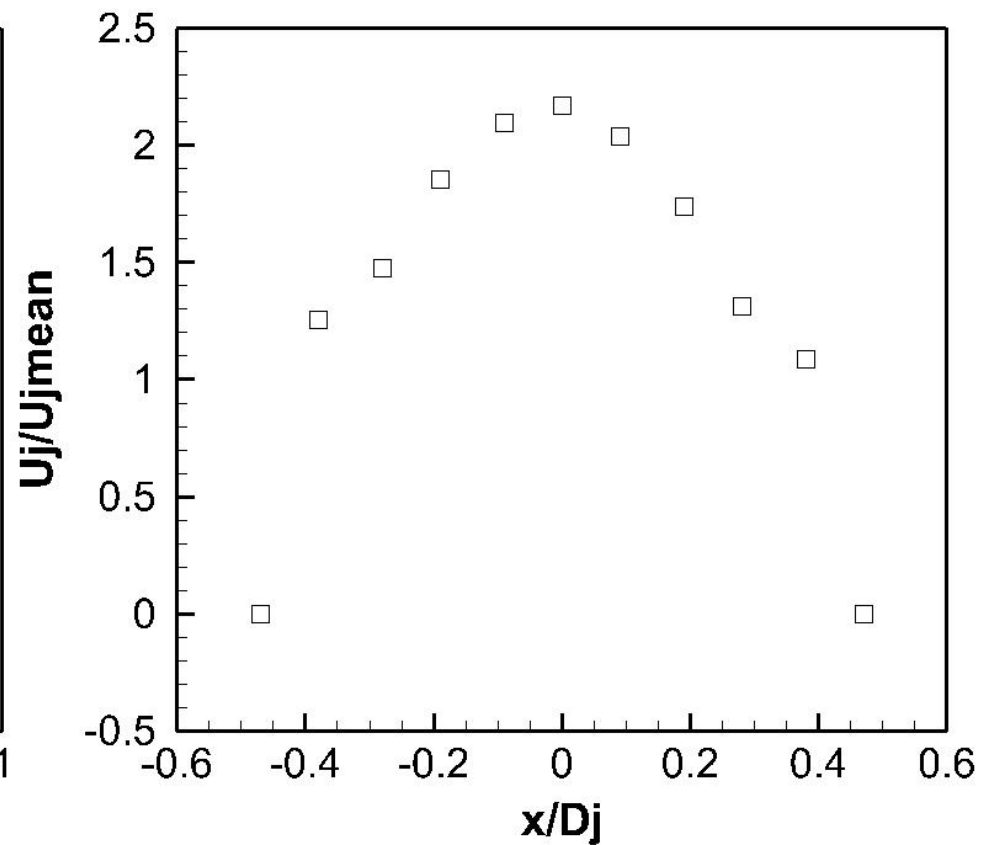


# Initial Conditions

## Crossflow



## Jet



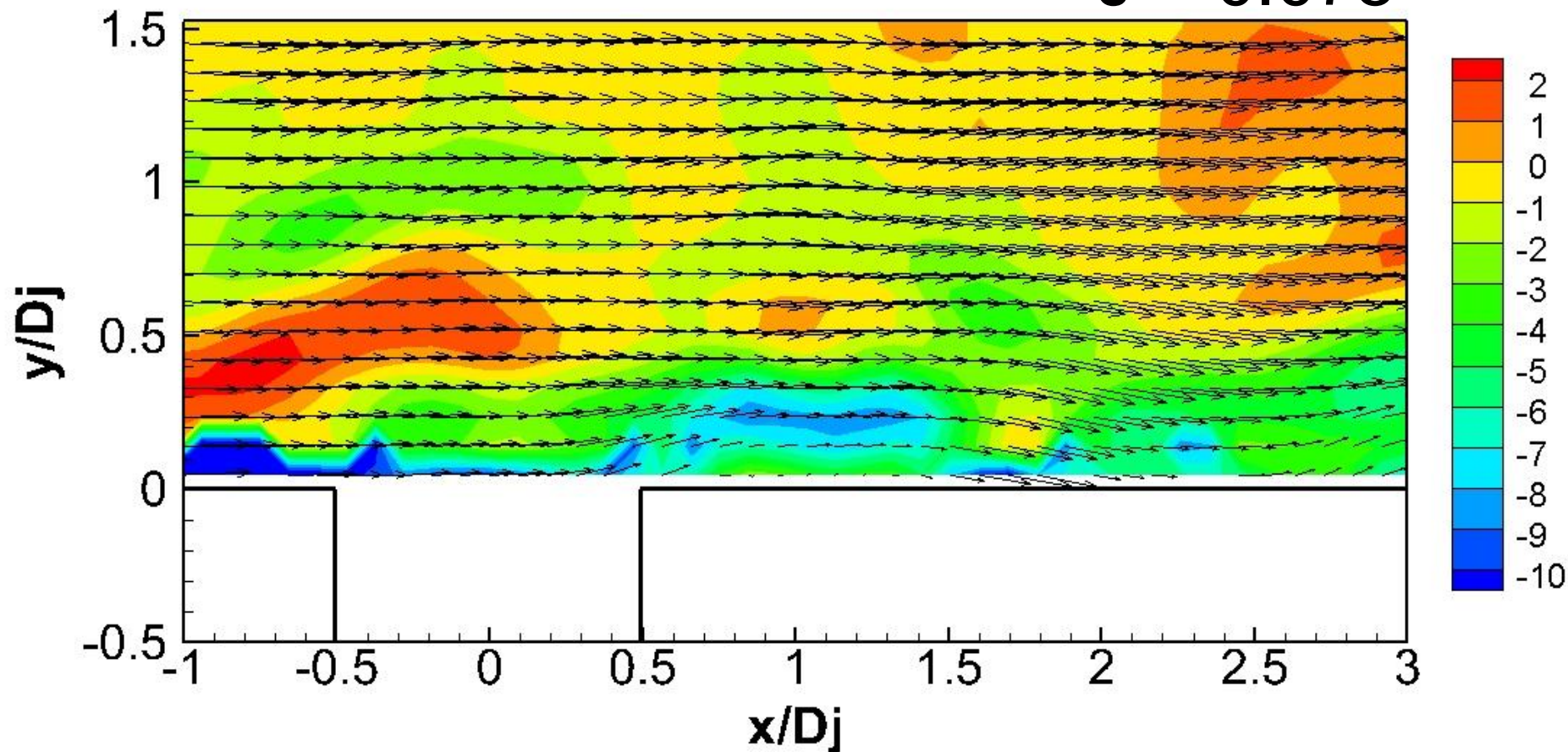




# Instantaneous Velocity Field

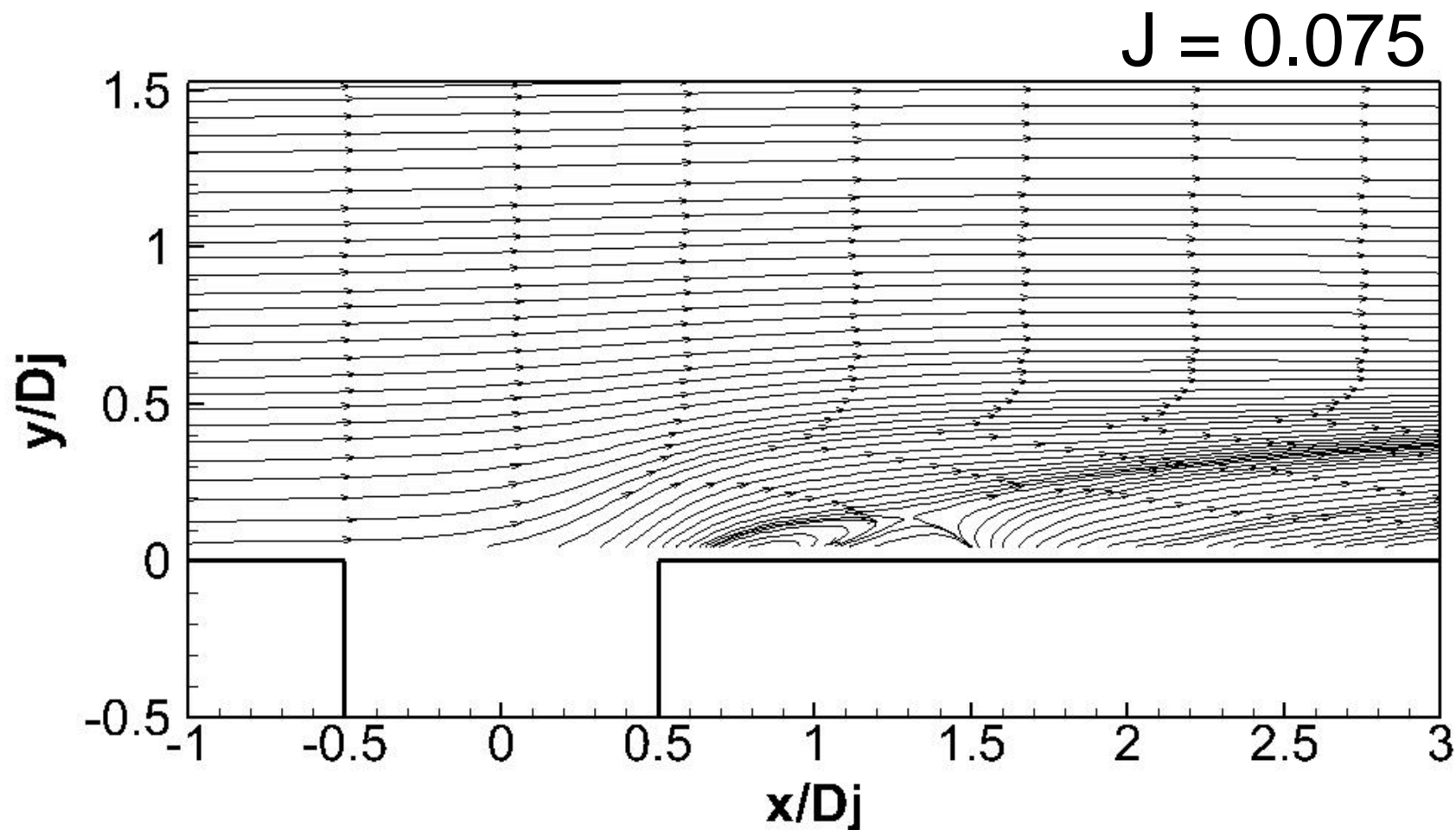


$$J = 0.075$$



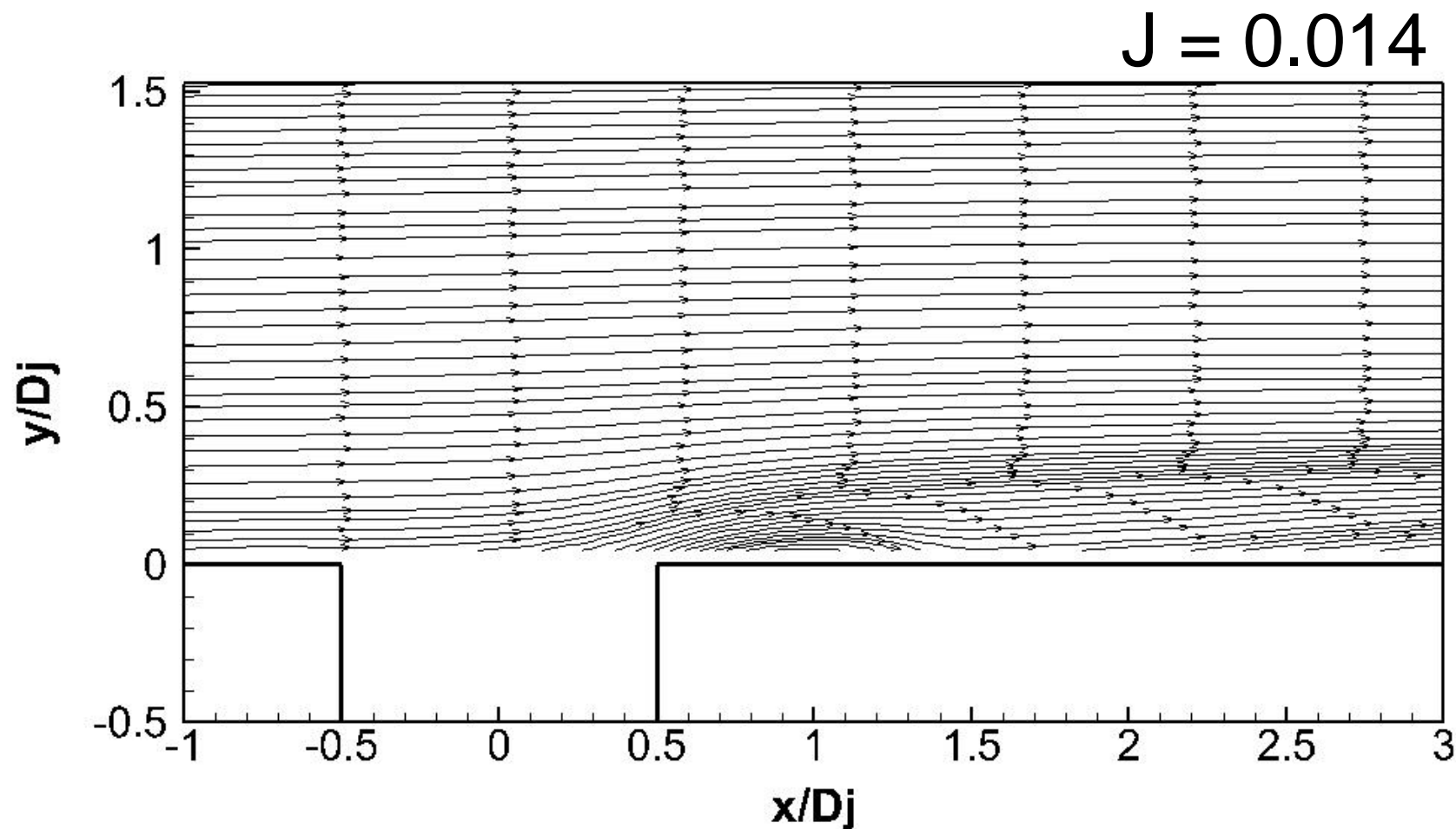


# Mean Velocity Field – Streamlines





# Mean Velocity Field – Streamlines

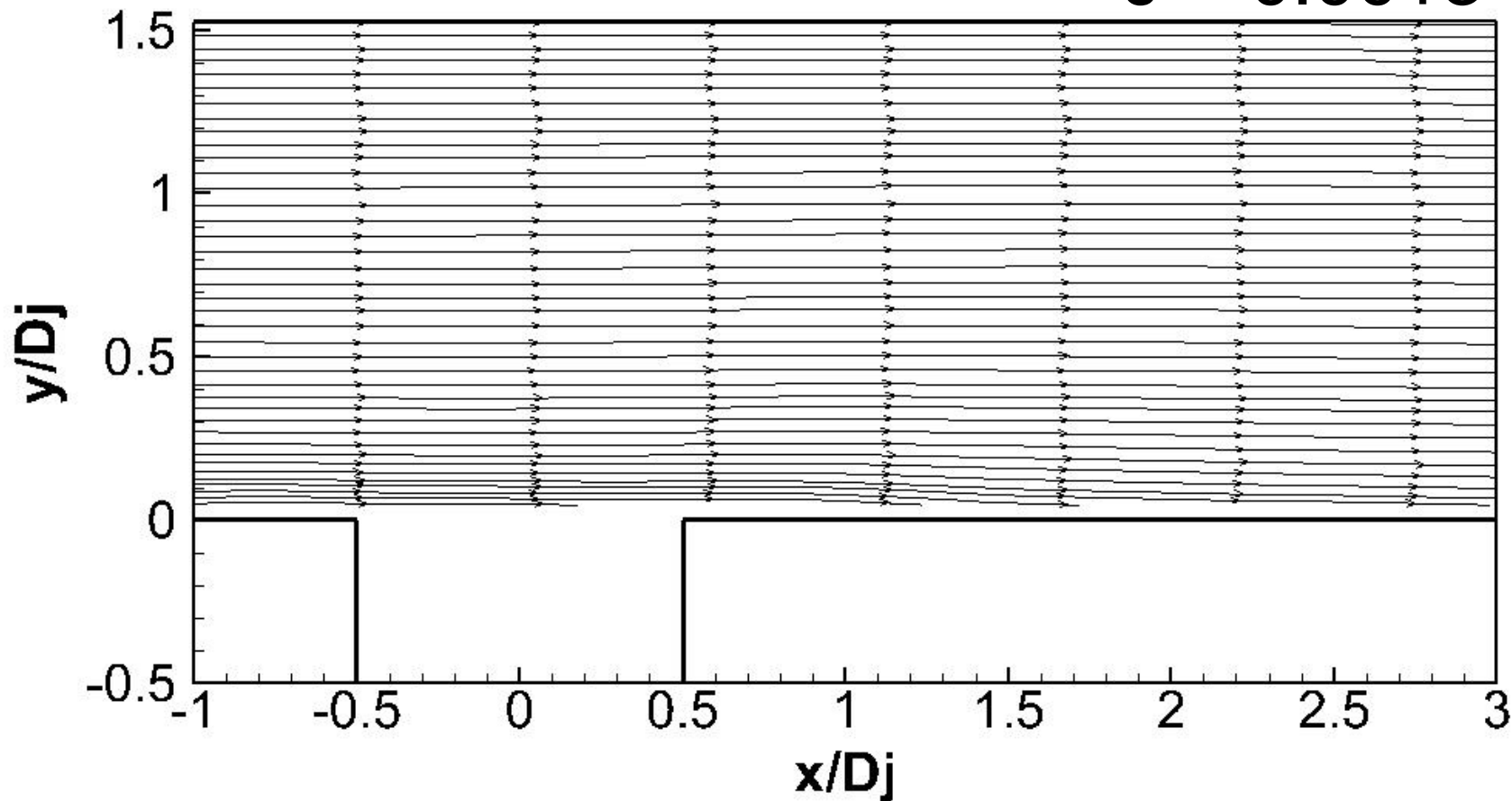




# Mean Velocity Field – Streamlines

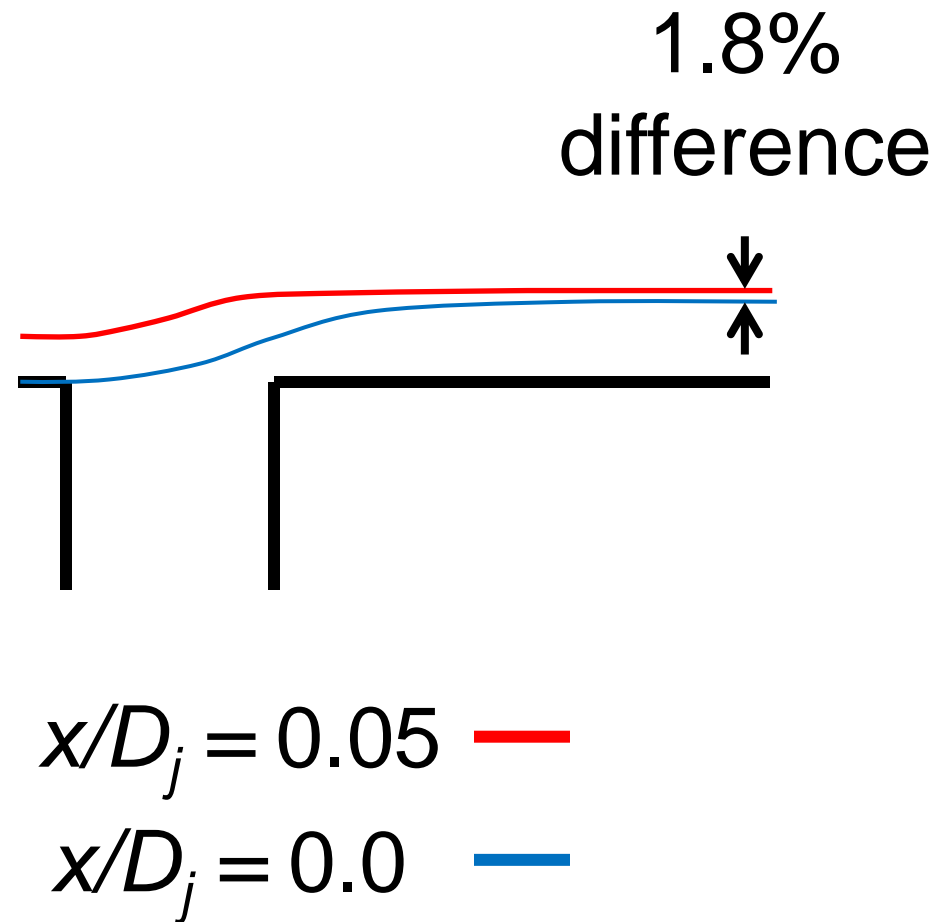
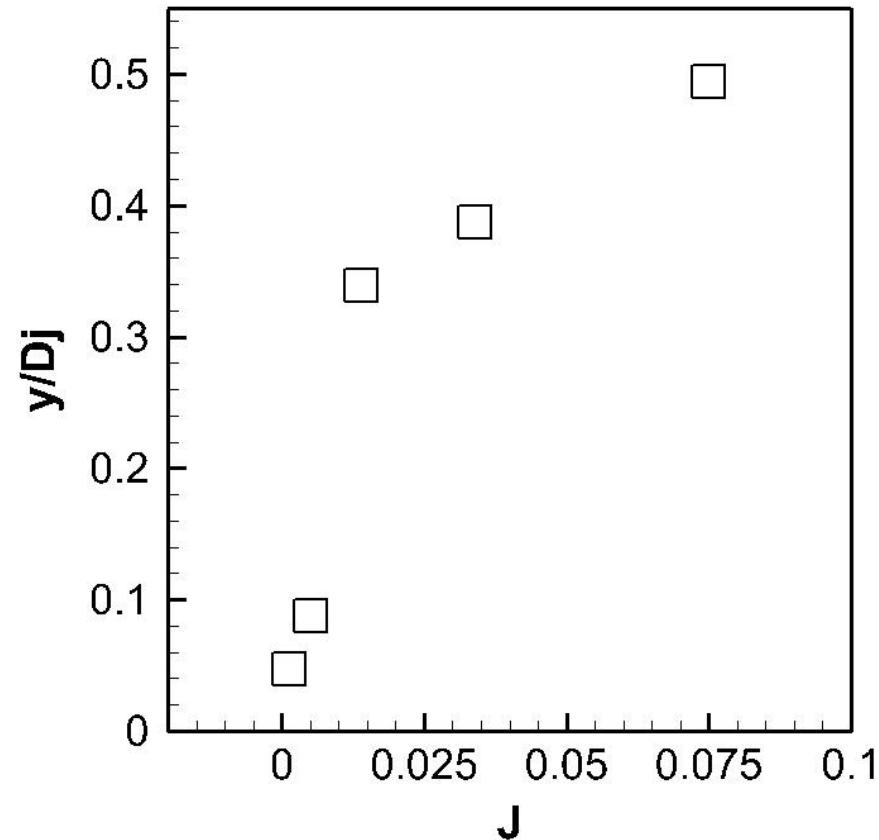


$$J = 0.0013$$



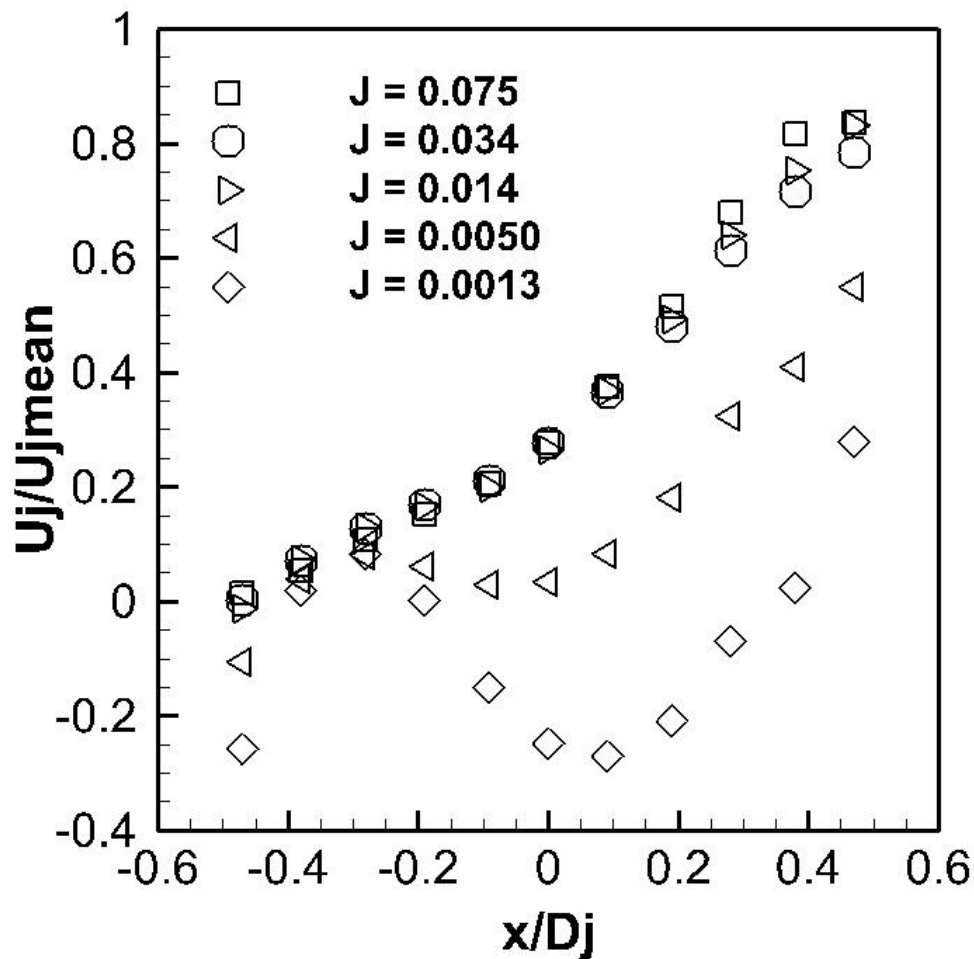


# Maximum Jet Penetration





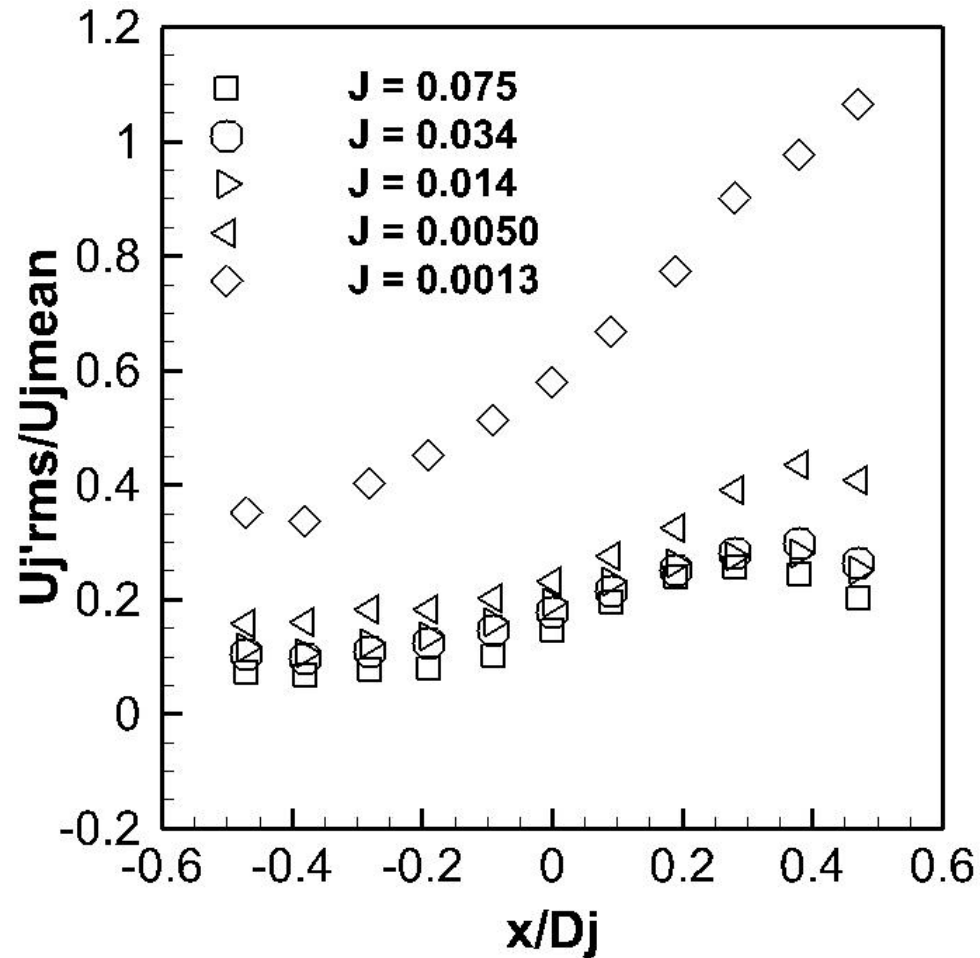
# Jet Exit – Velocity Profile





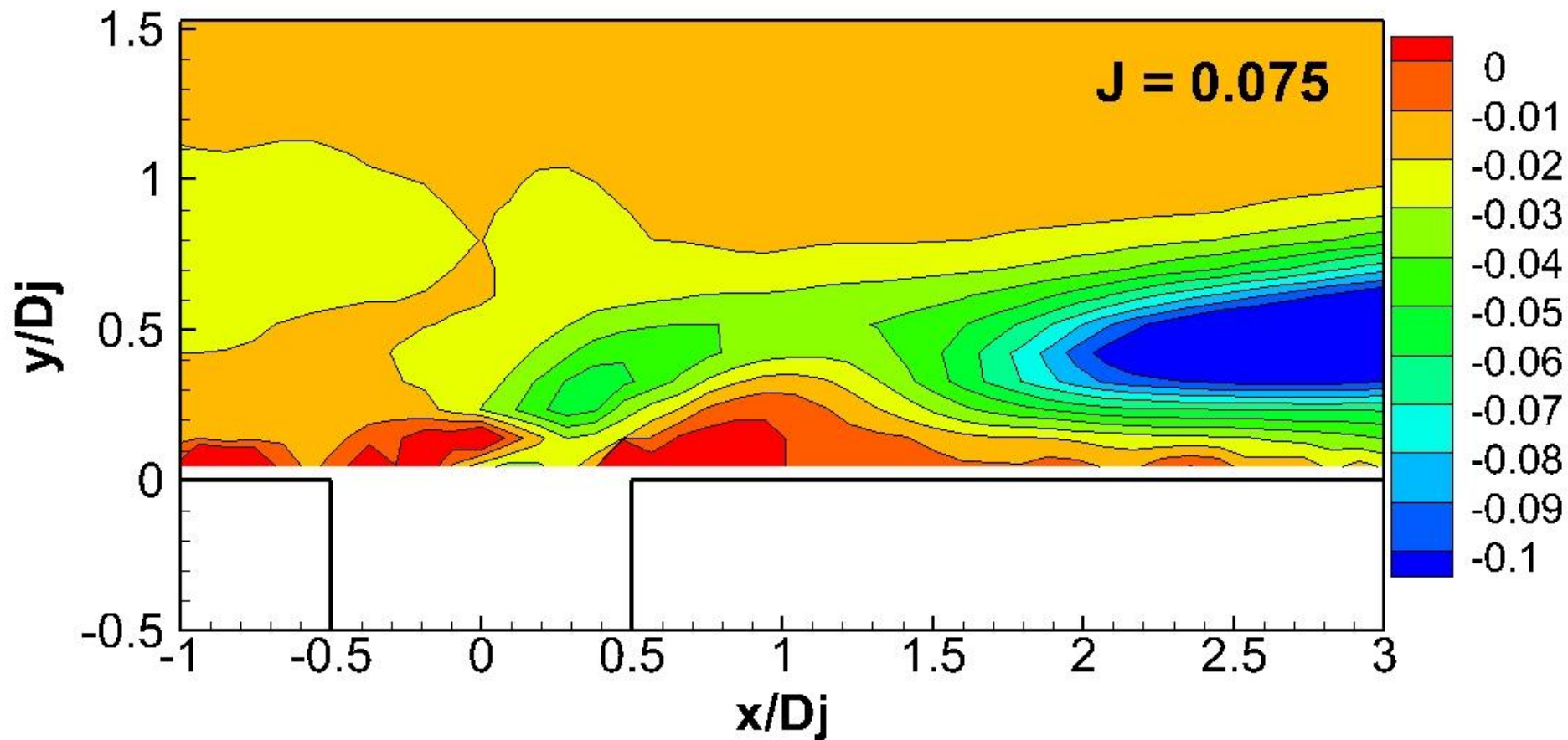


# Jet Exit – RMS Profile





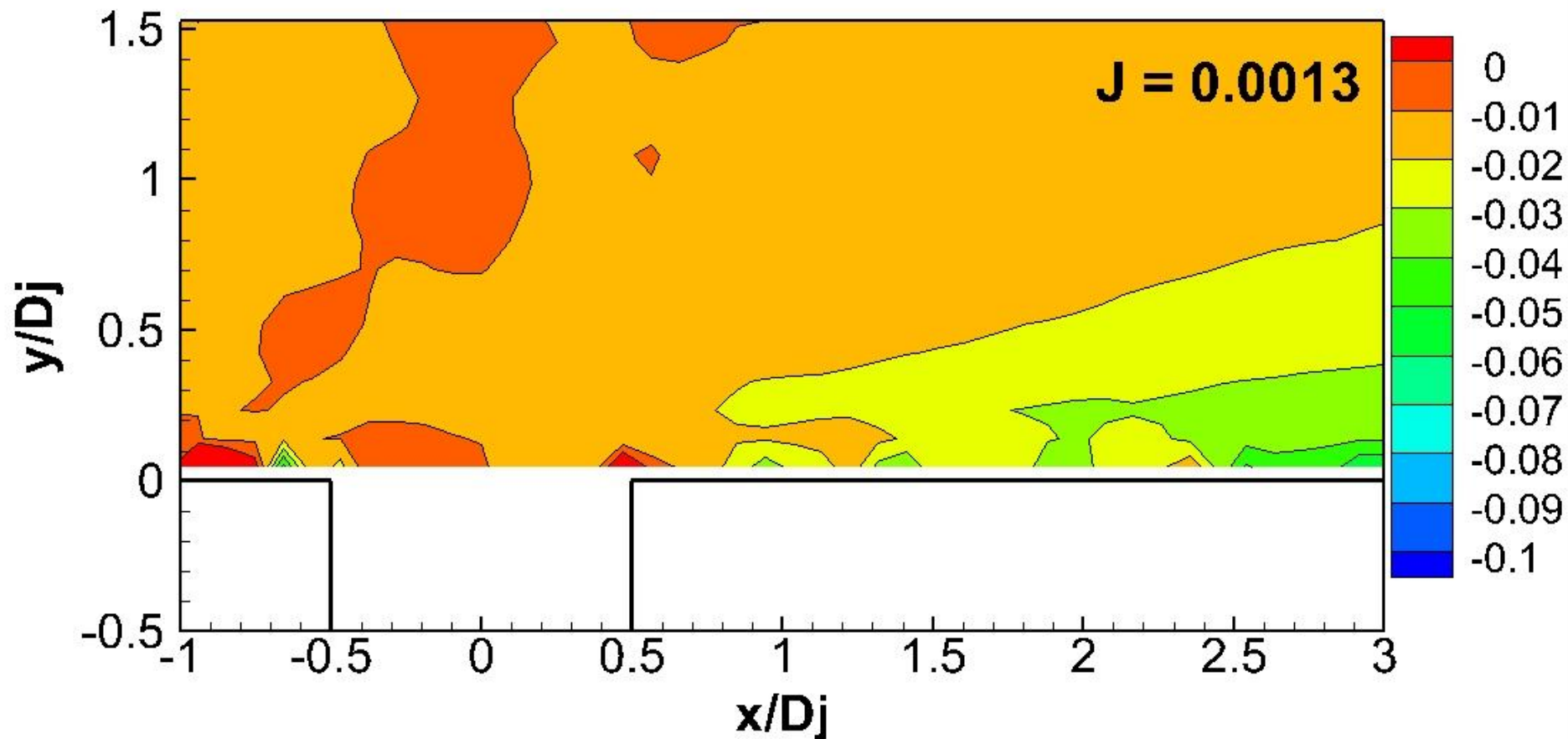
# Reynolds Shear Stress, $u'v'$





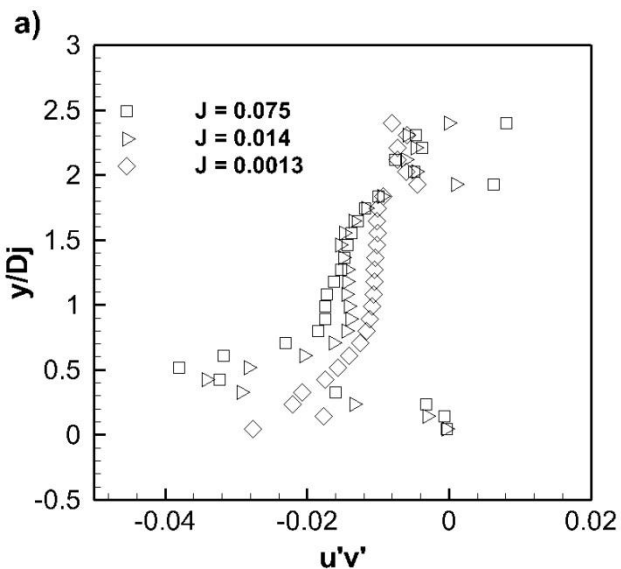


# Reynolds Shear Stress, $u'v'$

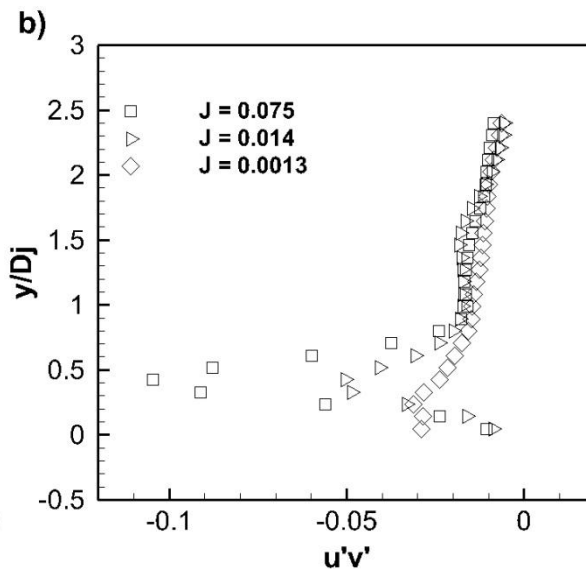




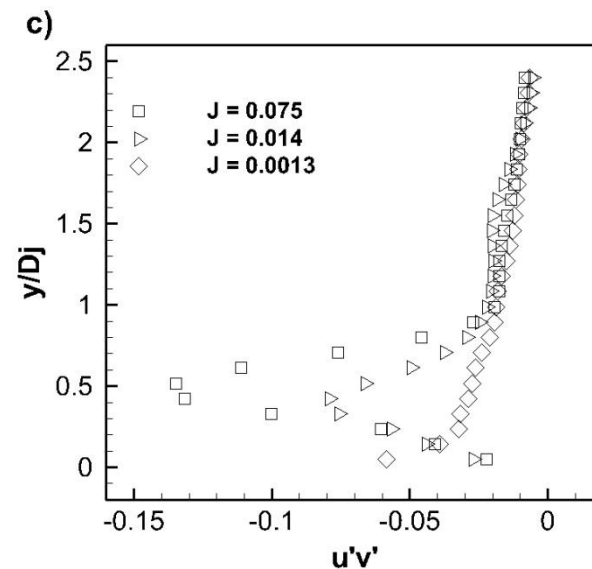
# Reynolds Shear Stress, $u'v'$



$$x/D_j = 1$$



$$x/D_j = 2$$



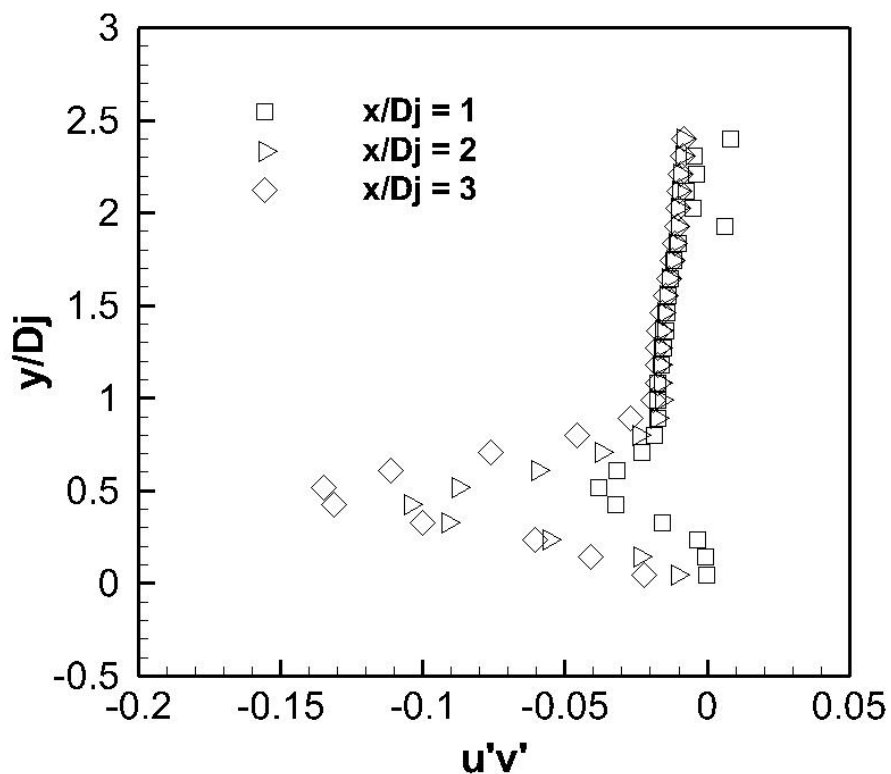
$$x/D_j = 3$$



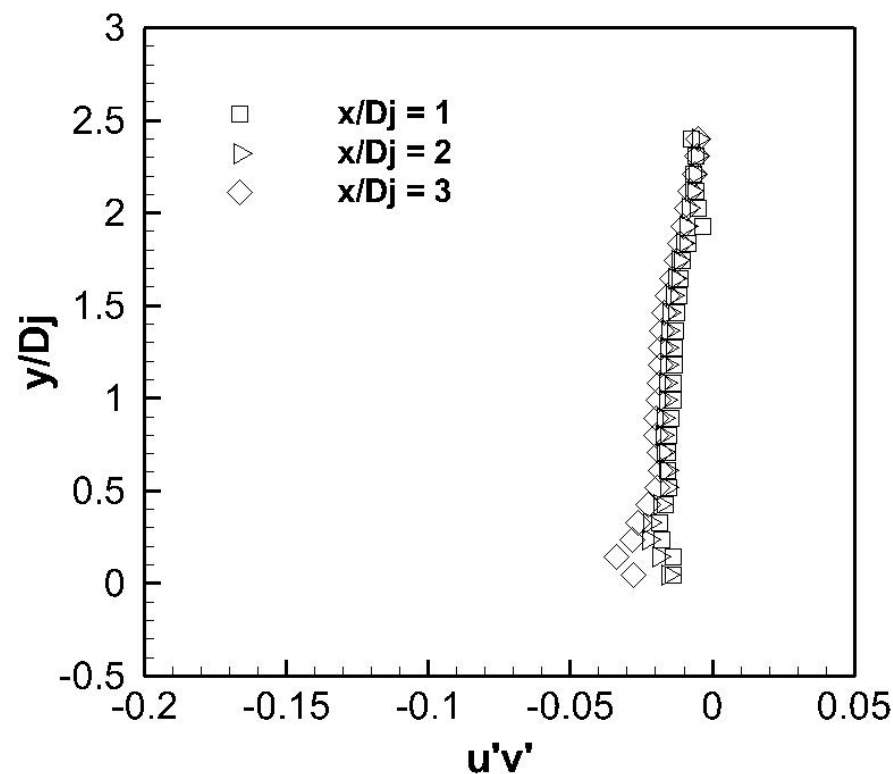
# Reynolds Shear Stress, $u'v'$



$J = 0.075$

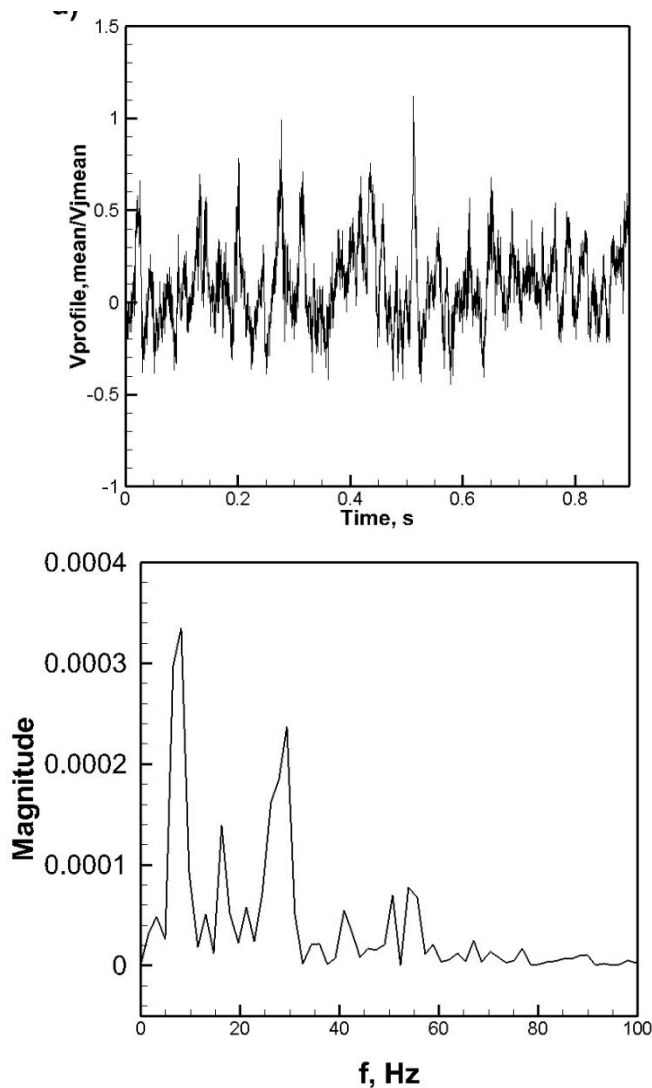


$J = 0.0013$



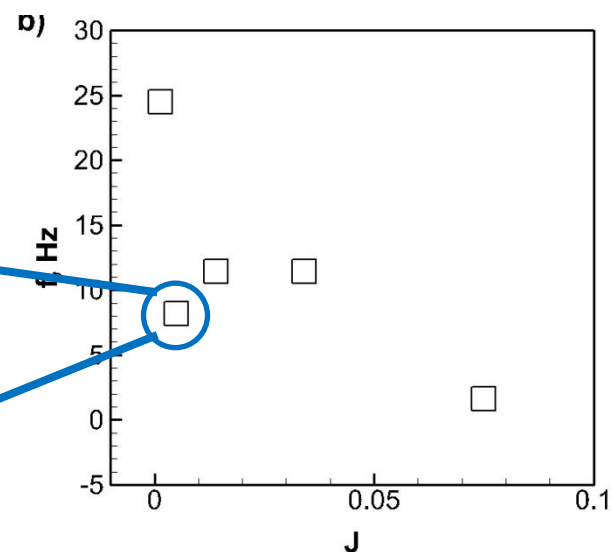


# Time Dependent Jet Behavior



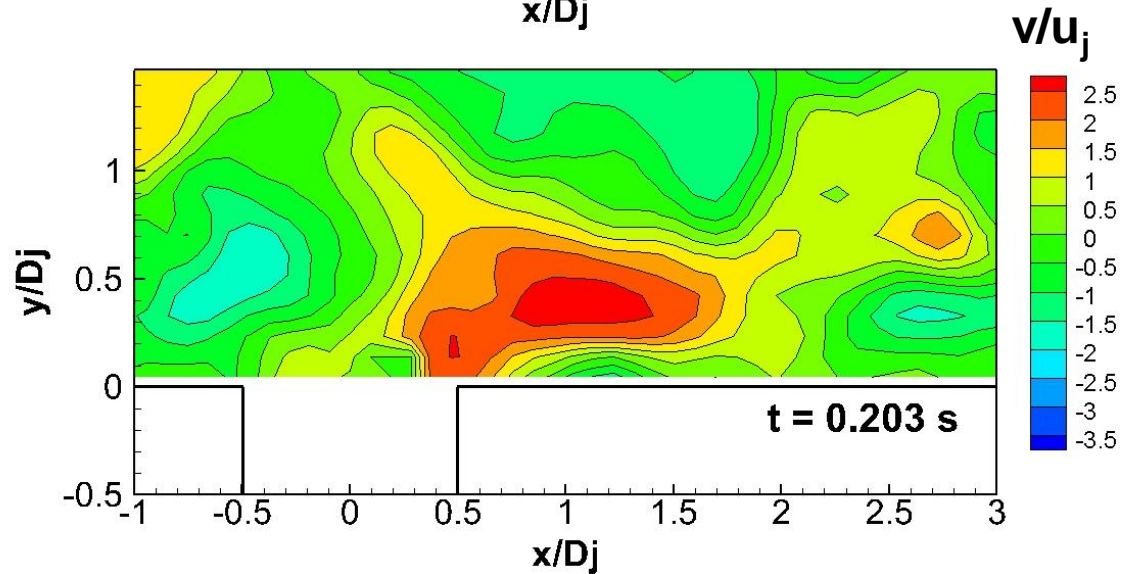
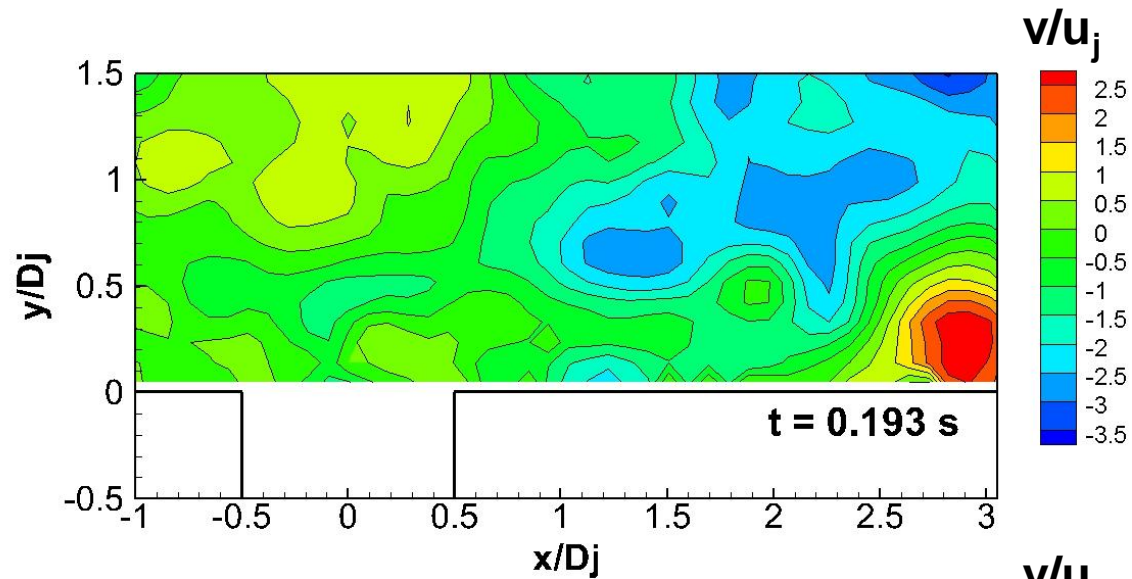
Time domain

Frequency domain





# Time Dependent Jet Behavior

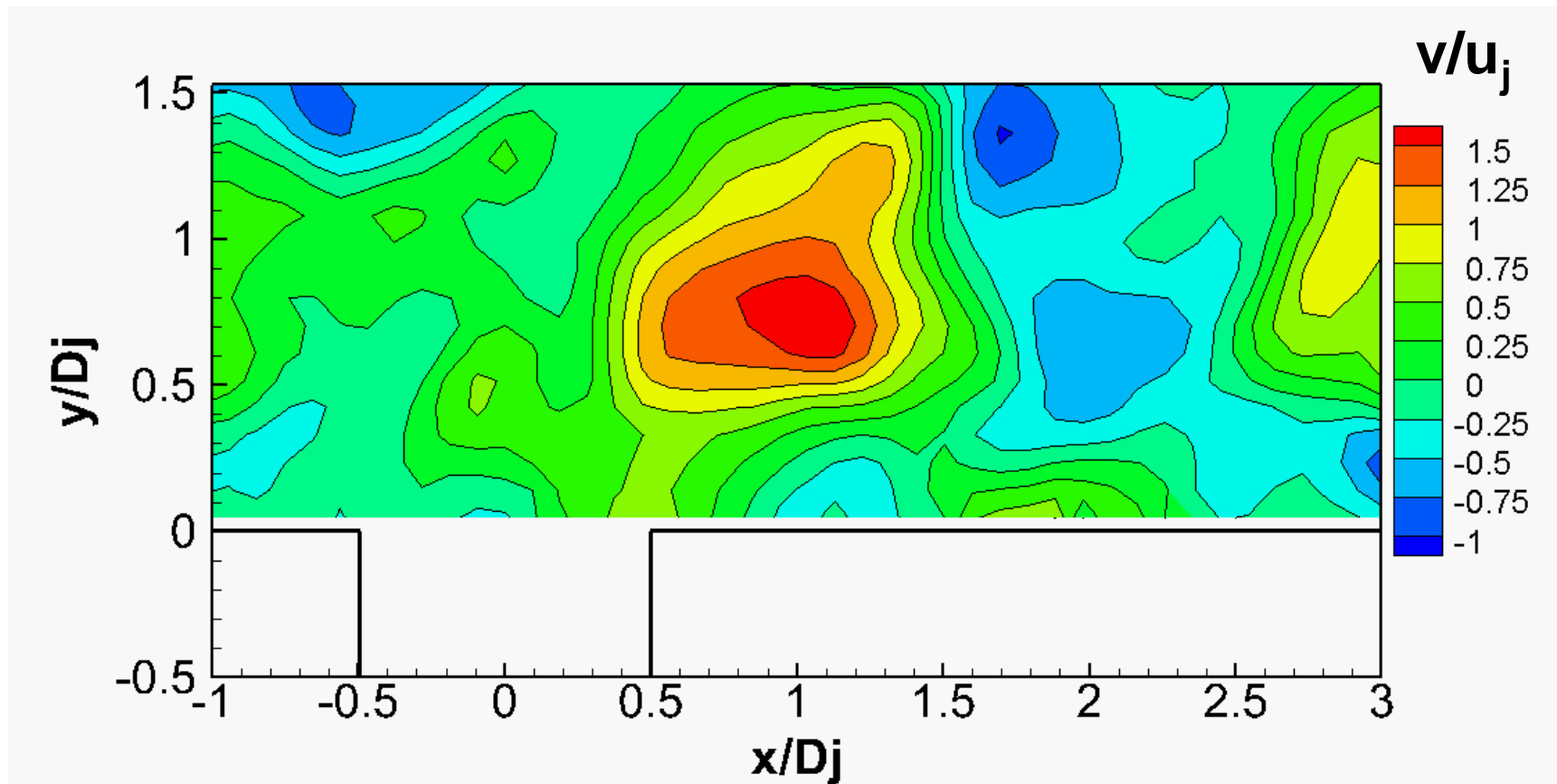




# Time Resolved Jet Behavior



$$J = 0.0050$$

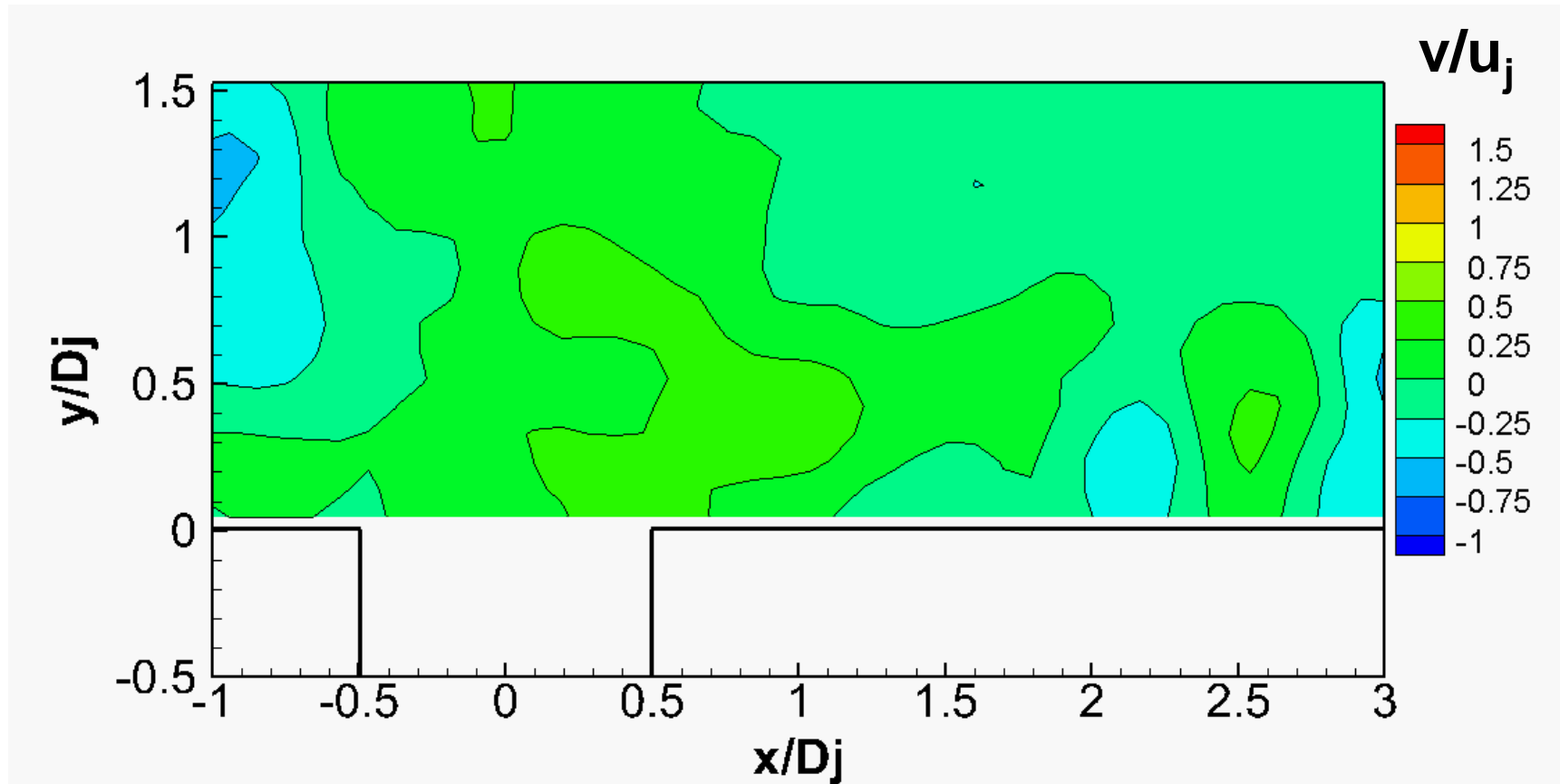




# Time Resolved Jet Behavior

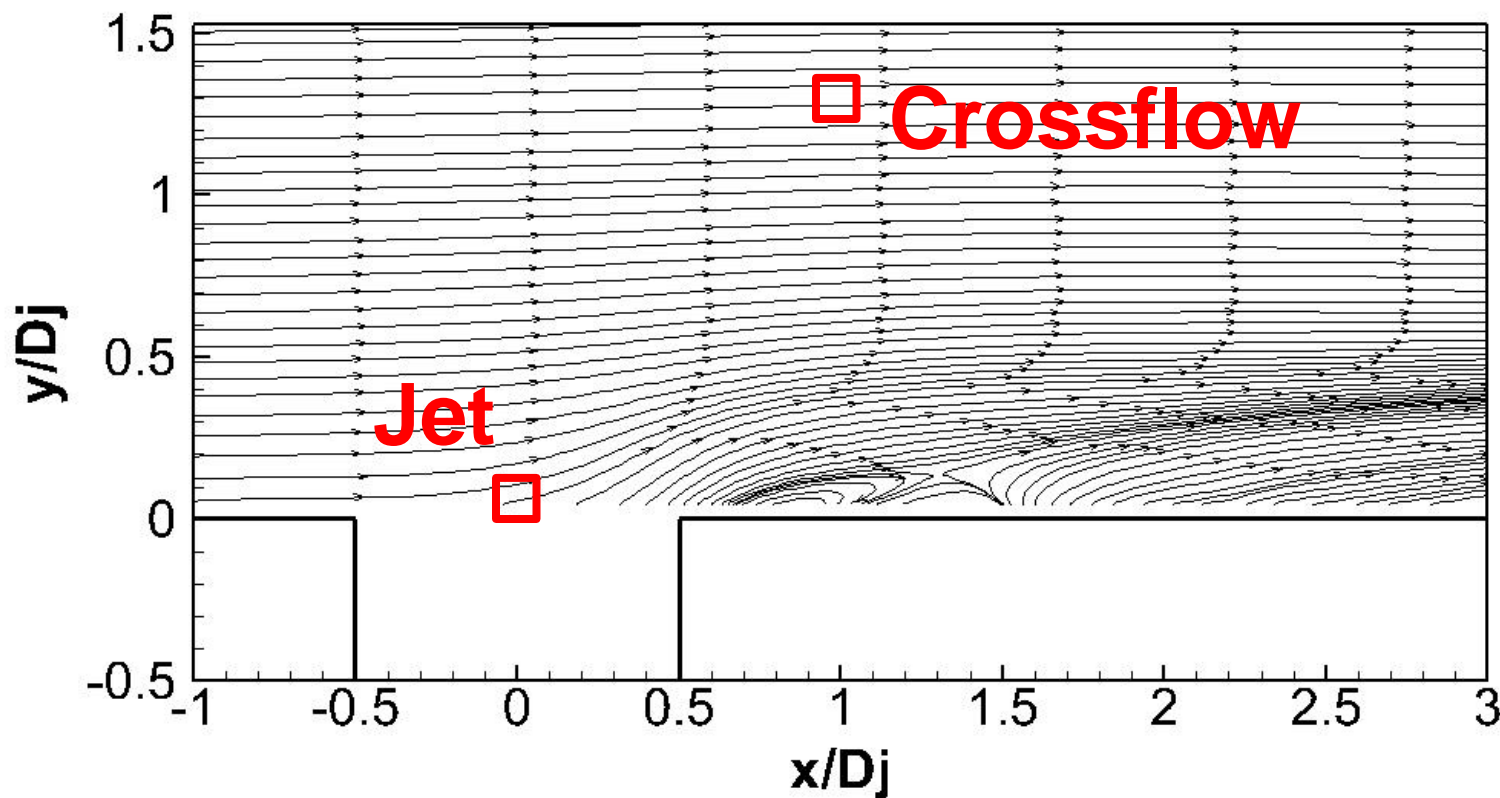


$$J = 0.075$$





# PIV Precision Uncertainty







# Precision Uncertainty – Jet



<i><b>J</b></i>	<i><b>u'<sup>2</sup></b></i>	<i><b>v'<sup>2</sup></b></i>	<i><b>u'v'</b></i>
<b>0.075</b>	0.0591	0.0045	0.0111
<b>0.014</b>	0.0655	0.0008	0.0068
<b>0.0013</b>	0.0844	0.0009	0.0064

$$u_{prec} = 2S_i / N^{1/2}$$

$S_i$  = standard deviation of  $i^{\text{th}}$  parameter

$N$  = number of samples (3,000)



# Conclusion



- **Confirmed jet and crossflow interaction for  $M = 0.275$  ( $J = 0.075$ )**
- **$J = 0.0013$  minimizes crossflow penetration**
- **$J = 0.0013$  is most unstable value of those studied**
- **PIV data provides evidence for highly 3-dimensional jet and crossflow interaction**
- **Reduced Reynolds shear stress values indicate potential improved performance of low momentum jets for use in film cooling applications**
- **Ingestion of crossflow fluid creates pulse-like jet behavior**



# Questions?





# Backup





# Precision Uncertainty – Jet



$J$	$u'$	$u'^2$	$\sqrt{u'^2}$	$v'$	$v'^2$	$\sqrt{v'^2}$	$u'v'$
<b>0.075</b>	0.0440	0.0591	0.0222	0.0084	0.0045	0.0057	0.0111
<b>0.034</b>	0.0532	0.0677	0.0235	0.0069	0.0019	0.0041	0.0095
<b>0.014</b>	0.0520	0.0655	0.0238	0.0048	0.0008	0.0028	0.0068
<b>0.0050</b>	0.0490	0.0714	0.0255	0.0033	0.0005	0.0021	0.0045
<b>0.0013</b>	0.0488	0.0844	0.0279	0.0042	0.0009	0.0027	0.0064



# Precision Uncertainty - Crossflow



$J$	$u'$	$u'^2$	$\sqrt{u'^2}$	$v'$	$v'^2$	$\sqrt{v'^2}$	$u'v'$
<b>0.075</b>	0.0186	0.0577	0.0123	0.0103	0.0051	0.0067	0.0053
<b>0.034</b>	0.0224	0.0961	0.0170	0.0098	0.0045	0.0063	0.0043
<b>0.014</b>	0.0195	0.0542	0.0127	0.0090	0.0036	0.0057	0.0044
<b>0.0050</b>	0.0218	0.0975	0.0167	0.0093	0.0042	0.0060	0.0043
<b>0.0013</b>	0.0170	0.0415	0.0109	0.0090	0.0038	0.0057	0.0051



# Experimental Conditions



- **Particle Image Velocimetry (PIV) Parameters**
  - 527 nm light source
  - 100 ns pulses
  - 0.5 mJ/pulse
  - Image-pair time separation = 120  $\mu$ s
  - Image-pair capture rate = 3348 Hz
  - Particle diameter = 1  $\mu$ m
  - 20 particle per 32 x 32 pixel interrogation region
- **Crossflow**
  - $Re_o = 14,000$
  - $u_o = 2.71$  m/s
- **Jet**
  - $62 < Re_j < 472$
  - $u_j = 0.731$  m/s